Evidences of Climate Change Signal at Local Scales in Ethiopia

G. Mengistu Tsidu[1] and Eyale Bayable[2]

Abstract —Earth's climate change is not a new phenomenon; it has occurred on all time scales throughout the Earth's history. However, climate change phenomena since the time of the mid eighteenth century are quite different from the changes occurred in the time of paleoclimatic and antiquity periods. The present day anthropogenically caused climate change is unique from its precedents in many respects and it has been bringing a serious challenge on life in different apocalyptic forms. This has a serious implication to Ethiopia since its economy is predominantly based on rain-fed agriculture. In this paper, climate change signals are detected at local scale in the country from analyses of precipitation data. Precipitation records from in-situ rain gauge measurements from over 190 stations are employed in the analysis which involves reconstruction of missing values, homogenization and gridding onto 0.5×0.5 degree. The monthly time series of girdded data are subjected to harmonic and singular spectrum analyses to see the seasonal cycles and trend components that predominantly account for the variability in the dataset. Harmonic analysis (HA) of the dataset reveals that the annual cycle accounts for 50 to 80% of the seasonal rainfall variability over northwestern and western parts as well as central and southeastern highlands of Ethiopia while the semiannual cycle accounts for 40% of seasonal rainfall variability over southern part of the country. A slow varying monotonic rainfall trend is detected using singular spectrum analysis (SSA). Mann- Kendall test is applied to determine statistical significance of the detected trend. The results reveal that almost all of the grid points show either significant increasing or decreasing trend at both 95% and 99% significant levels. Spatially, parts of southern Ethiopia with a bimodal rain type and some parts of western half of the country, which has a monomodal type long rainy season, have shown decreasing rainfall trend. Southeastern highlands and most of the southeastern lowlands have also exhibited long term decline in rainfall. The north and northeastern part of the country and very localized places of western Ethiopia have exhibited an increase in rainfall for the last 30 years. The rainfall over the central rift valley areas has been deceasing whereas it has been increasing over the southern rift valley areas.

Keywords — Climate change, harmonic analysis, rainfall trend, singular spectrum analysis

1 INTRODUCTION

Studies on impact assessments of climate change show that Africa in general and the sub-Saharan Africa countries in particular are likely among the most vulnerable to climate change. Ethiopia is in the sub Saharan Africa region whose economy is predominantly agriculture which is very much dependent on rainfall. The weak economy denies the country the capability of taking proactive as well as remedial actions against impacts resulting from vulnerability to climate variability and change (NMA, 2007). Moreover, food insecurity is one of the urgent issues of the country. As a result, agriculture is viewed as the driving force of the economy and a means of ensuring the national food security.

However, the effectiveness of such agriculture led economy has been challenged by different impeding factors. Among all factors, climate related problems have the lion share. Because the county's economy is sensitive to climate variability, it has been confirmed that variations in average rainfall of preceding year is directly proportional to growth/decline in GDP of current year in Ethiopia (Thornton et al., 2006; Yeshanew and Jury, 2006).

Despite the fact that climate change impacts have severe potential on developing nations, African governments do not recognize the link between development and climate change, regarding the latter as a distant future problem. However, climate change will determine which crops can be grown where in the coming decades. This will cause profound challenges for subsistence Ethiopian farmers and pastoralists since they lack the resources to adopt alternative livelihood strategies. Climate change and its impacts, therefore, are cases for concern to Ethiopia.

Present climate studies are primarily focused on detection and attribution of climate change. A number of studies in different parts of the world on a continental and subcontinental spatial scales have been performed to find a detectable human influence on past climate change which is manifested mainly by a change in temperature, precipitation, sea level rise, mountain glaciers, and discharge of rivers. For instance, Stott (2003) detects the warming effects of increasing green house gas concentrations in six continental–scale regions over the 1900 to 2000 periods, using HadCM3 Simulations. Zwiers and Zhang (2003) also detect the anthropogenic influence on climate change over the 1950 to 2000 periods in serious nested regions, beginning with the full global domains and descending to separate continental domains for North America and Eurasia. A more comprehensive study of Knutson (2006) which covers between 0.3 and 7.4% of the area of the globe including tropical and extra tropical land and ocean regions suggests that there is a detectable anthropogenic warming signal over many of the regions he examined. Although the evidence is weaker than at continental scale, anthropogenic signals can now also be detected in some subcontinental scale areas using formal detection methods. Zhang et al. (2006) detect anthropogenic fingerprints in China and southern Canada. Spagnoli et al. (2002) find some evidence for a human influence on 30-year trends of summer daily minimum temperatures in France. Min et al. (2005) find an anthropogenic influence on East Asian temperature changes in a Bayesian framework.

Studies have also applied on attribution analysis to sub-continental temperatures to make inferences about changes in related variables. Stott et al. (2004) detect an anthropogenic influence on southern European Summer mean temperature changes of the past 50 years and then infer the likelihood of exceeding an extreme temperature threshold. Gillett et al. (2004a) detect an anthropogenic contribution to summer season warming in Canada and demonstrate a statistical link with area burned in forest fires.

Similar to atmospheric and surface temperature, precipitation is also another most important climate variable which is used in contributing further evidence of climate change. Because the amount of moisture in the atmosphere is expected to increase in a warming climate as saturation vapor pressure increases with temperature according to the Clausius – Clapeyron equation (Trenberth et al., 2005). Green house gas increases are also expected to cause enhanced horizontal transport of water vapor that is expected to lead to a drying of the subtropics and parts of the tropics (Kumar et al., 2004; Neelin, 2006), and a further increase in precipitation in the equatorial region and at high latitudes (Emori and brown, 2005; Held and Soden, 2006).

Despite this fact, African governments are mainly concerned with poverty reduction, health and education service, water, land degradation and conflict policies (McCarthy et al., 2001). Little resources are allocated at national level, since climate is seen as a lesser priority compared to other “urgent needs” (Elasha et al., 2006). As a result, the African continent lags behind other regions in terms of availability of detailed scientific knowledge of its climate, in partiular, there are a few climate change studies at its subcontinental regions.

The conclusions of the present few climate studies in Africa are similar to that of the global. The regional climate projection of IPCC Fourth report (2007) on Africa claimed that all of Africa is very likely to warm during this century. The warming is even very likely to be larger than the global, annual mean warming throughout the continent and in all seasons, with drier subtropical regions warming more than the moist tropics. This shows that there is a change in temperature and precipitation. In the works of Malhi and Wright (2004), decadal warming rates of 0.29^0C in the African tropical forest and 0.1-0.3^0C in South Africa have been observed. There was an increase in the number of warm spells over southern and western Africa, and a decrease in the number of extremely cold days in the periods between 1960-2000 (New et al., 2006). Minimum temperatures have increased slightly faster than maximum or mean temperatures in South Africa and Ethiopia (Conway et al., 2004; Kruger and Shongue, 2004). Decreasing trends in temperature from weather stations located close to the coast or to major inland lakes have been observed in Eastern Africa (King’ Uyu et al., 2000).

Rainfall also exhibits notable spatial variability in the continent. Because even without any change in total precipitation, higher temperatures in the continent lead to a greater proportion of total precipitation in heavy and very heavy precipitation events due to the positive feedback that comes from the atmospheric water vapor to enhance further evaporation. Since the amount of moisture in the atmosphere is likely to rise much faster as a consequence of rising temperature than the total precipitation, this should lead to an increase in intensity of extreme precipitation in some places and deficit in others. This will offset the normal hydrological cycles by decreasing the duration or frequency of different events. As stated in the regional projection of the fourth Assessment report of IPCC, East Africa is the only region in which there is a likely increase in annual rainfall and the rest has a likelihood of decrement. But the region has been experiencing an intensifying dipole rain pattern on the decadal time-scale and the dipole is characterized by increasing rainfall over the northern sector and decline amounts over the southern sector (Schreck and Semazzi, 2004) during recent decades.

Local climate studies are needed to provide fine-scale climate information for impact assessment and adaptation purposes (Elasha et al., 2006) because climate impacts occur locally and can take many different forms in different places. As the signal of climate change strengthens, change in surface temperature and precipitation detection is becoming possible at increasingly smaller scales locally even at a country level (Stott and Tett, 1998). This particularly shows an important insight for local climate studies in areas characterized by a diverse and heterogeneous land surfaces like Ethiopia, a country where extreme weather variations, such as floods and droughts are increasing in magnitude and frequency in recent times, since the different surfaces have different degree of vulnerability.

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However, climate change study at the national level in Ethiopia is at its infant stage; there are limited numbers of quantitative impact assessments made so far on various socio-economic sectors in the country (NMA, 2007).

The purpose of this paper is to assess evidences of climate change signal at country level from analysis of 30 years gridded rainfall data spanning a period of 1978-2007. The paper is organized such that description of the study area is given in Section 2. Section 3 describes the data set and different methods used for the analysis where as Section 4 gives results and discussions. Finally, conclusions are given in Section 5.

2 DESCRIPTION OF THE STUDY AREA

Ethiopia lies in the tropics, however, due to its high altitude mountains, the tropical climate is somehow rectified and a good part of the country enjoys a temperate climate type.

Most of the western Ethiopia as well as the highlands of south and the east have tropical rainy climate; while the highlands in southwest have warm temperate and tropical rainy climates (Gonfa, 1996). Ethiopian's climate is characterized by high rainfall and temperature variability in both spatial and temporal scales. The variability in distribution is related with altitude, latitude, humidity and winds which are the significant factors in affecting the weather system of the area.

Temperature varies greatly with altitude. Temporally, there is a seasonal variability of the mean maximum and minimum temperatures in the country. The 'Belg' months (March, April, and May) are the warmest months almost all over the country when the annual extreme maximum temperatures are observed in many places. The 'Bega' months (November, December and January) are the coldest months.

Because of Ethiopia's location, the Indian Ocean, the Atlantic Ocean and both the African and the Asian landmasses have strong influences on the seasonal and climatic behavior of the country. The seasonal and annual rainfall variations in Ethiopia are associated with the macro-scale pressure system on the oceans (St. Helena and Mascarena) as well as monsoon winds originating from the oceans (Mekonnen, 1998; Seleshi and Zanke, 2004; G/Eyesus, 2006; Jember, 2007). Since the sources of moisture are the Indian and Atlantic Ocean, the position and strength of the high pressure systems in these oceans as well as the strength of the jet which transports moistures from the Indian Oceans and the presence of monsoon winds from Guinea and heat lows over Sudan/Chad will have controlling roles on the amount of moisture transported to Ethiopia. As a result, Ethiopian's climate is the combined effects of the macro pressure systems coiled in the two oceans and other driving systems. These driving systems are Inter-Tropical Convergence Zone, Subtropical Jet (STJ), Tropical Easterly jet, Red Sea Convergence Zone, and the Somali Jet.

3 DATA AND METHODOLOGY

3.1 Data set

Although climate studies are basically dependant on observational records of meteorological variables, the problem of data discontinuity in time and space which often lead to missing records of the different meteorological variables are common in the real world. Particularly, climate observing systems in Africa is rather in worse state than any other continent and is deteriorating (Washington et al., 2004). Moreover, the life style in hostile lowland areas of Ethiopia may not encourage successive observational meteorological data recording tasks. All these factors have their own share of contribution for climate data scarcity and gaps in the country. To reject all incomplete series would mean the discarding of almost all data in most African states.

Moreover, climate data is suffered from inhomogeneity. A homogeneous climate time series is defined as one where variations are caused only by variations in climate (Aguilar et. al., 2003). However, besides the missing problem, most long term climate data could also be affected by a number of non-climatic factors such as relocation of an observatory, changes in instrumentation, changes of the station environment or in reading procedures, as well as human errors in data processing and this has the potential of making the data unrepresentative of the actual climate variation occurring over time. Involvements of such non-climatic factors can bias a time series and lead to misinterpretations of the studied climate. It is important, therefore, to remove the inhomogeneous data by doing homogeneity test prior to performing the main analysis. The homogeneity test and adjustment for inhomogeneity are performed using the RHtestsV3 software package which detects multiple change points and includes provision of Quantile-Matching adjustments (Wang et al., 2010) in addition to mean-adjustment provided in the older version; choice of the segment to which the base series is to be adjusted, and choices of the nominal level of confidence at which to conduct the test. The results show that about 30% of the initially selected stations were inhomogeneous (Mengistu Tsidu, 2011).

Some of the adjusted rainfall time series for inhomogeneity have also missing values. Hence, there is a need to fill the missing data. We used the regularized expectation maximization (REM) algorithm (Schneider, 2001) for filling missing data. REM algorithm is based on iterative analysis of linear regressions of variables with missing values on variables with available values, with regression coefficients estimated by ridge regression. In a few cases, reconstruction of the time series has been done to have a 30 year data for all the stations (Mengistu Tsidu, 2011).

The data set has been gridded onto a regular 0.5 degree resolution along both latitude and longitude using Universal Kriging. The quality and self-consistence of the data set have been validated against CRU, CMAP and GPCP data sets. The homogenization by RHtestV3 software package,, data gap filling based on advanced REM algorithm, gridding of the resulting data set using Universal Kriging, quality and self-consistence of the data set against CRU, CMAP and GPCP data sets have been reported in detail (Mengistu Tsidu, 2011).

3.2 Methodology

Since basic climatological features over any region are hidden in many meteorological variables, especially in precipitation records, the periodical phenomena of these variables in different harmonics are the most important one in depicting the features. Hence harmonic analysis (HA), which is one of the frequency domain analyses of temporal data, seems most compatible with this objective.

HA describes quantitatively the cyclical behavior of variables. A time dependant data series that repeats itself every t time intervals can, therefore, be represented by a series of harmonic functions (Fourier series) and their frequencies are multiples of a base (fundamental) frequency. Therefore, the dominant cyclic mode of variability of rainfall over Ethiopia is identified from amplitude of HA functions while time of occurrence of peak rainfall is determined from their phases.

It has been argued in several previous studies (Ghil et al., 1997) that singular spectrum analysis (SSA) is useful in nonlinear system analysis because there is no need to choose the structure function apriori but the data themselves choose the temporal structures. Suppose we have time series of length N, choose some maximum lag M and compute the $M \times M$ lag autocovariance matrix, whose elements are given by

$$C_{ij} = \frac{1}{N-M}\sum_{k=1}^{N-M} x(k+i)x(k+j) \qquad (1)$$

We can then carryout the eigenanalysis of this matrix to get temporal structures that explain the maximum possible amount of temporal autocovariance on an interval of measure M. The eigenvalues will be the amount of covariance in time explained by each eigenvector. The time series can then be reconstructed at any point n by expanding the data in the basis set of eigenfunctions:

$$x(n) = \sum_{k=1}^{M} \sum_{i+j=n} a_k(i) e_k(j) \qquad (2)$$

where $e_k(j)$ is the jth element of the kth egienvector, and $a_k(i)$ is an expansion coefficient beginning at the point i.

All trends considered in this study are tested for significance with Mann-Kendall trend test. Being a function of the ranks of the observations rather than their actual values, this test is not affected by the actual distribution of the data and is less sensitive to outliers and it is the most robust as well as suitable for detecting trends in precipitation which are usually skewed and may be contaminated with outliers.

4 Results and Discussions

The HA of gridded rainfall data over Ethiopia are conducted to determine the dominant periodic components in the variability of rainfall over Ethiopia. Moreover, the trends of rainfall data on a grid of resolution 0.5×0.5 degree over Ethiopia are determined and their statistical significances are tested using Mann Kendall's trend significant test with the levels of significance at 0.01 ($z_{\alpha/2}$=±2.58) and 0.05($z_{\alpha/2}$=±1.96). The spatial distribution of the two dominant cyclic components, trend and its significance is discussed in the next sections. The normalized spectral density chosen randomly from available grids is also presented in the following section to see available periodic components in the rainfall time series over the country.

4.1 Dominant Seasonal Components and Timing of Peak Rainfalls

Knowledge of peak rainfall timing is crucial because it is closely related with maximum potentials of stream flow, groundwater recharge. The annual rainfall variation accounts for upto 80 % of the seasonal variability over nearly western half of the country as shown in Fig. 4.1 (top panel) while the semiannual variation shown in Fig.4.1 (bottom panel) accounts for upto 45 % of the seasonal variability over the southern regions of the country. The annual variability peaks during the months of mid-June to mid-August over western half and southeastern highlands of the country (see Fig.4.2, top panel).

The semiannual mode of rainfall variability peaks during the months of mid-March to mid-April during the first half of the year and mid-September to mid-October during the second half of the year over the southern parts of the country as depicted in Fig.4.2 (bottom panel). The amplitude and phase analyses reveal the monomodal and bimodal rainfall distributions in a more robust manner than the previous studies.

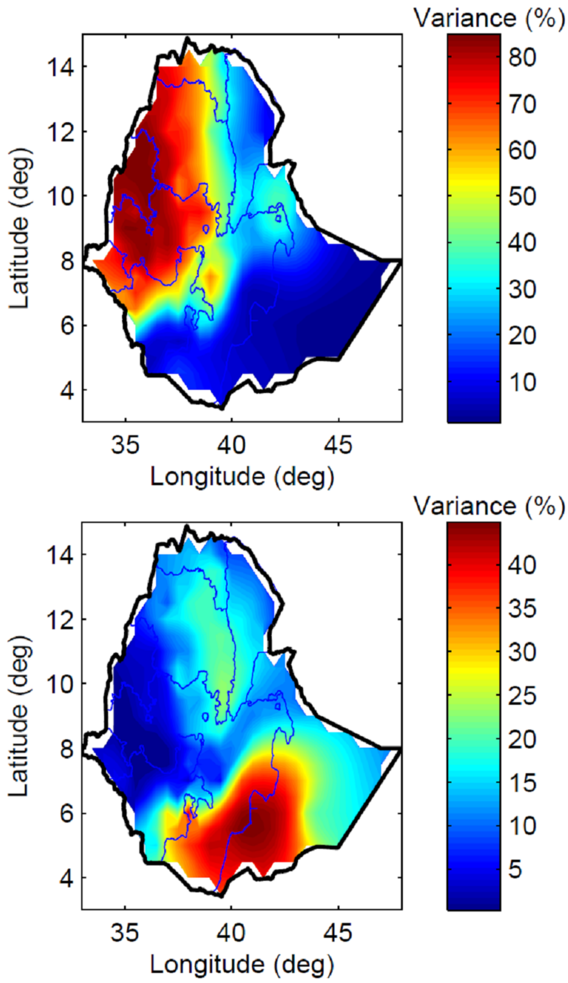

Fig.4.1. The two dominant seasonal modes: annual (top) and semiannual (bottom).

The southernmost and southeastern parts of the country mostly receive maximum rainfall twice in a year in the months of April and May during the first half of the year and September and October during the second half as shown in Fig. 4.2 (bootom panel) whereas the northern and western parts receive in July and August as depicted in Fig. 4.2 (top panel). The spatial difference in time when peak rainfall occurs and the northward advancing phase patterns show great similarity with rainfall "clusters" identified over Ethiopia by Gissila et al. (2004).

As climate change manifests itself by impeding with the natural climate variability of a region, it has a potential of changing both the intensity of rainfall and its time of peak rainfall. In the customary popular "rainfall calendar" of Ethiopia, rainfall intensity advances gradually since its onset and becomes maximum around mid of the season, although there are regional differences in the time of rainy season.

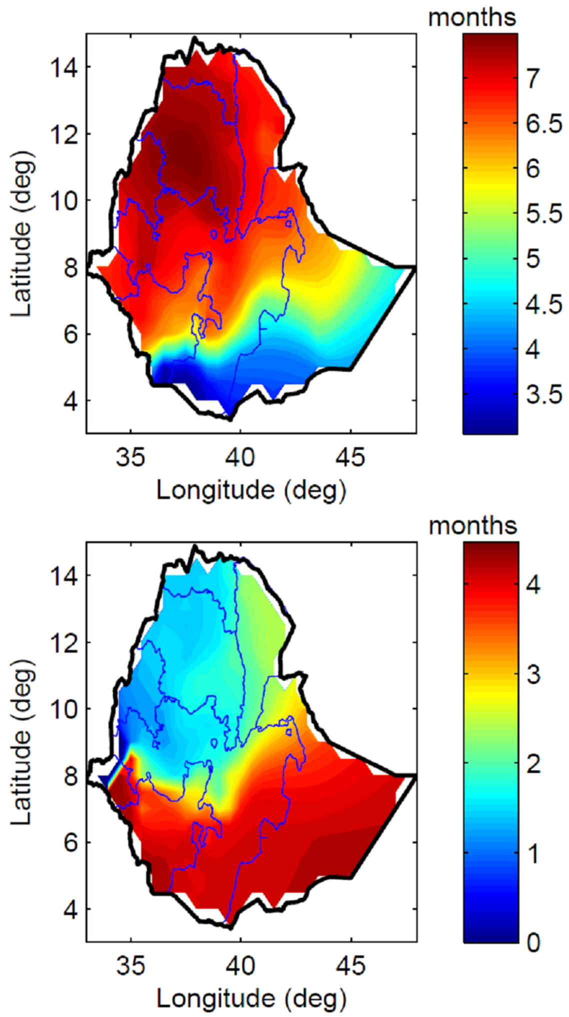

Fig.4.2. The two phases of dominant seasonal modes: annual (top) and semiannual (bottom).

4.2 Rainfall Trend

Trend detection can be done by simple linear curve fitting to the raw time series. However, other signals of higher frequencies and noise in the data drammatically affect the quality of linear fit and thereby the value of trend determined. The trend has been also determined by decomposing the original time series into mean, cyclic components, trend and noise using HA. However, it is really difficult to know what are the processes that contribute to the periodic components of the time series apriori. As a result what is termed as trend and noise could be part of cyclic processes that can be explained by higher harmonics. This uncertainty makes difficult to use HA for trend detection. The are also other powerful emprical techniques such as emprical mode decomposition (EMD) but sensitive to end effects. However, SSA is robust and has no known limitation. Fig. 4.3 (2nd and 5th panels) shows slowly varying trend components at two grid points over the country selected randomly. Once the slow varying component is selected, it is straightforward to fit linear curve whose slope is trend of the rainfall time series. The first and the fourth panels of Fig.4.3 represent the rainfall along with the fitted curves to slowly varying components. The third and the last panels of the figure represent the all the remaining components.

Fig.4.4 shows normalized spectral density of the two time series at the selected grid points. There are processes that contribute substantially to the rainfall variability with a periodicity of 0.5, 1.0, 2.5, 3.5, 5.0, 10-11 years as depicted in both panels of Fig,4.4.

The spatial distribution of z-score of Mann-Kandall trend test shown in Fig.4.5 shows that there are significant increasing and decreasing rainfall trends over Ethiopia. Decrease in rainfall is most pronounced in western part of western highlands and lowlands of western Ethiopia, central rift valley and adjoinig highlands and southeastern highlands of the country. The southern rift valley and adjoing southwestern highland, northern rift valley and adjoining northwestern highlands, northern part of central highlnads, north and northeastern highlands of the country expreincedan increase in rainfall over the years. Small areas of northwestern and southeastern part of ogaden region expreinced increasing rainfall while the remaining part of somali region witnessed decreasing in rainfall. However, due to data scarcity, the gridded data over this region is not trustworthy.

The general spatial distribution of precipitation trend shows that almost all of the western parts of the country have a decreasing trend in rainfall despite the difference in amount. However, with the exception of the small bordering areas of Sudan, most of the western half of the country is claimed to be a very less drought probability incidence zone for a long period of time (NMSA, 1996b; Degefu, 1987). The less drought probability zone of the country seems to be changing as precipitation decreases in recent years. Receiving rainfall during the Ethiopian Kiremt season, this region (the western half) has a monomodal type of rainfall and it is the wettest part in the country in which rainfall is common for extended periods (from two to ten months) of the year even if raining duration decreases as one goes from south to north.

The seasonal moisture sources of Ethiopia are the Atlantic/Congo basin and Indian Oceans although the individual contribution to a specific region of the country is not yet quantified (Mekonnen, 1998). There may be a spatial difference in predominance of moisture contribution to the specific regions of the country because of numerous factors like the inter-annual variability of ITCZ position, the strength of moisture carrying winds and jets as well as other factors.

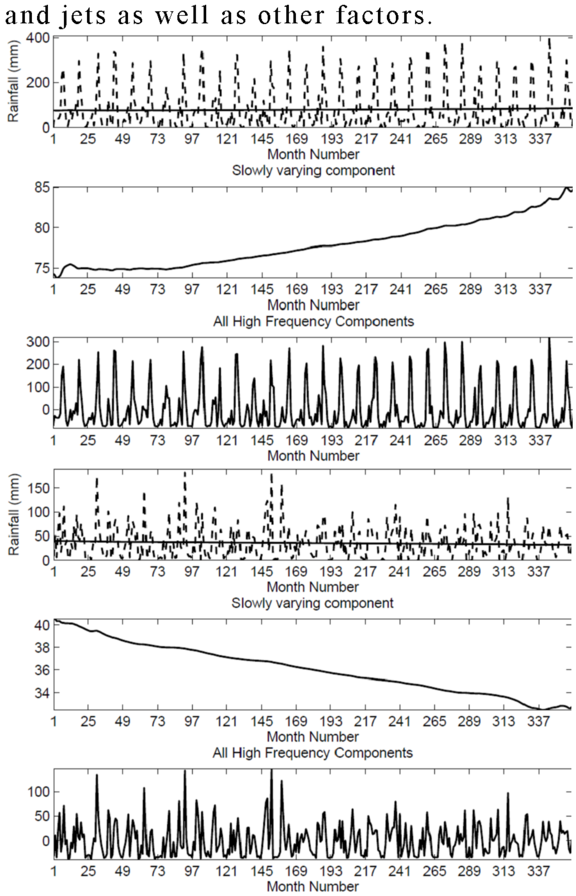

Fig.4.3. SSA analysis for two random selected grids: Increasing rainfall trend (three top panels) and decreasing rainfall trend (three bottom panels).

Studies done by Parker and Folland (1991) show that because of the green house gas induced climate change, the tropical South

Atlantic Ocean has become warm and this has a paramount impact on the rain bearing systems of Ethiopia in general and southwestern parts in particular.

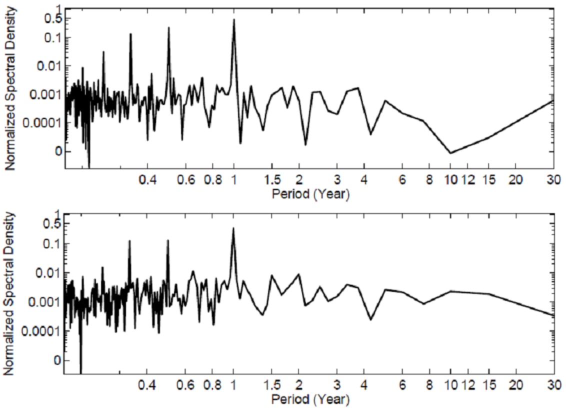

Fig.4.4. Normalized spectral density of rainfall at the two random selected grids.

Correlation studies by Seleshi and Zanke (2004) have indicated that the persistent declines in rainfall at south in Neghele, at southwestern in Masha and Gore are caused by the corresponding persistent warming of the South Atlantic Ocean over the period of the 20th century. Seleshi and Zanke (2004) have also correlated precipitation patterns of selected Ethiopian meteorological stations with the ever increasing temperature and pressure anomalies of both Atlantic and pacific oceans. They founded that, in general, the warmer the South Atlantic Ocean and the higher the pressure over the tropical Eastern Pacific Ocean, the less the Kiremt rain is over the southwestern, south and Eastern Ethiopia. The result of our study seems to agree with their findings given the South Atlantic Ocean is warming. However, there are some contrary results to our findings. For instance, part of the Seleshi and Zanke (2004) work claimed that there is no trend in annual and seasonal total rain over central, northern and northwest Ethiopia in contrary to significant trends that are revealed in our work as shown in Figs. 4.5-4.6. Part of the NMSA (2001) works claimed that precipitation in central Ethiopia has increasing trend. However in this work, we have found that their claim is true for northern part of central Ethiopia while central rift valley and adjoining central highlands and southeastern highlands have seen that they do have a significant decreasing rainfall trend. The results reported by Seleshi and Zanke (2004) are based on annual and seasonal total and suffered from limitation reported in Section 3. Moreover, annual and seasonal total can hide some of the small variations attributable to climate change. Therefore, the discrepancy shows that climate change signal requires advanced statistical analyis tools such as EMD and SSA to detect trend in rainfall time series particularily smaller ones.

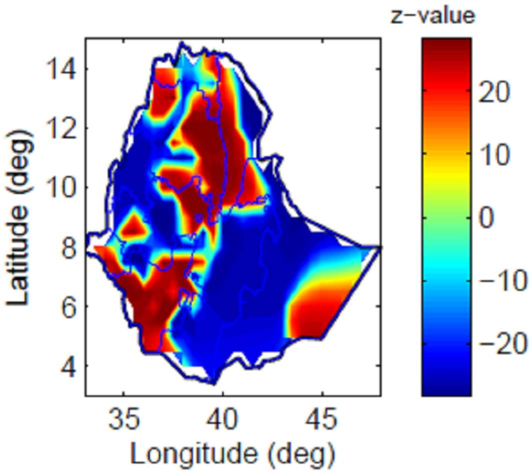

Fig.4.5. The Mann-Kandall z-score for significance rainfall trend test.

The small but significant deccrease in rainfall shown in western parts of the northern highlands (with the exception of small areas bordering Sudan) could also be related to altertion in moisture derivers. In addition to the combined moisture contributions from Atlantic/Congo, these parts of the country have got moisture mainly from the Indian Ocean. This is particularly true during the Belg Ethiopian Season. The rises in Sea surface Temperature Anomaly (SSTA) patterns over the South Atlantic Ocean have their own shares in influencing the recurrence of drought in Ethiopia (Folland et al., 1986) by decreasing the moisture influx and its impact can be extended to the northeastern parts the country.

Analogous to its Atlantic counterparts, the southern part of the Indian Ocean is also becoming warm due to global climate change. Many literatures have shown this observed reality. The tropical Indian Ocean has warmed over the 20th century and the rate of warming has accelerated substantially during the last 30 years (WCRP, 2006). These changes played a key role in shaping important features of climate variability and change that have huge impacts worldwide from drying trend of African Sahel (Giannini et al., 2003) to the pacific decadal variability (Deser et al., 2004) to the North Atlantic Oscillation (Hoerling et al., 2004).

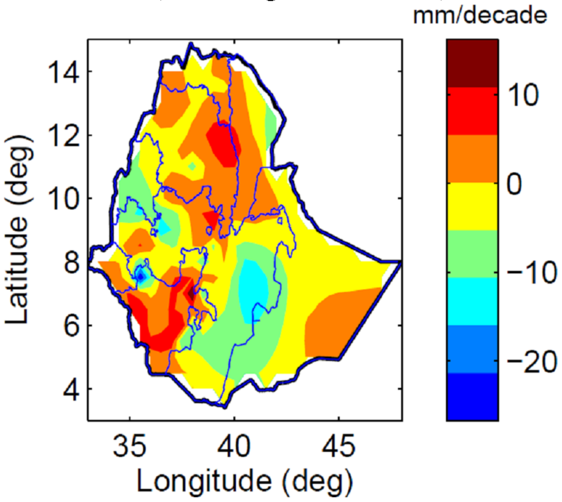

Fig.4.6. The rainfall trend over Ethiopia.

Locally, within the Indian Ocean region, the monsoon circulation has steadily weakened over the last 50 years (Sperber et al., 2000) and this seems to be related to the Indian Ocean warming resulted in a reduction in land-sea contrast in temperature, which in turn creates conducive conditions for the occurrence of cyclones over the ocean and the ultimate reduction of moisture transportation to the nearby Ethiopian regions. The study done by Shanko and Camberlin (1998) on the relation between the Indian Ocean cyclone and nature of precipitation in Ethiopia show that there has been consecutive occurrence of several tropical depressions over the southwestern Indian Ocean (SWIO) and this coincides with a decrease in rainfall and frequent droughts in Ethiopia. Moreover, their work has also claimed that Belg rainfall is much more influenced by the cyclonic activity than Kiremt rainfall since the latter season occurs outside the cyclonic season of the southeast Indian Ocean. As a result, totally, the northern half of the country is claimed to be showing a year to year decreasing trend in rainfall (NMSA, 2001). The GCM simulations by Folland et al. (1986) have also shown the impact of the anomalous SST features of the north Indian Ocean on the rainfall variation in Sudan and Ethiopia as well as its contribution to drought in the region. On the contrary, other scholars have contended that there is no proven decline change of rainfall in north and northeastern Ethiopia especially during recent three or four decades (Conway, 2000; Hausken, 2004). Our results agree with finding of scholars who argue the importance of Indian Ocean warming in decrease in rainfal in north western highlands as well as western part of central highlands for the last three decades. Seleshi and Zanke (2004) also failed to find a declining trend over the northwestern highlands of Ethiopia since the recent two decades. These researchers argue for the presence of drought in the region but the attribution could not be the decline in rainfall rather some other factors like the change in nature of the rainfall, environmental degradation as well as the pervasive local socioeconomic problems. Our results, which shows increase in rainfal over northeastern highlands, confirm conclusion of Hausken (2004), who argues that the frequent recurrence of the so called drought in northeast Ethiopia may not be necessarily related to declining trend of rainfall. The study of Conway (2000) also indicates that the nature of rainfall since 1990s has become more humid as compared to the 1980s dry episode in the areas of Wollo and Tigray. The increasing rainfall trends of our findings in the area can give us clues about the persistency of the 1990s and the ever increasing rainfall trend in the last few years. Moreover, some recent climate models also indicate that there is a likelihood of wetter mean conditions in the future over parts of Northern Ethiopia bordering the Red Sea with a shift in rainy season with October receiving more rainfall than the present climate (www.knmi.nl/africa_scenarios). The physical mechanism how rainfall increase is not clear and needs further investigation.

Rainfall trend in rift valley region is very fascinating and imperative. Contrary to their physiographical similarities, e.g. topography, availability of lakes, the precipitation trend has a dichotomized nature. It has decreased in central rift valley areas like Ziway, Metehara, Awassa as well as the nearby highlands like Abomsa and increased in the lower southern rift valley areas of Arba Minch and Dilla.

Most of the central rift valley region has a semi-arid climate type and endowed with dotted natural lakes. Characterized by three distinct seasons, this part of the rift valley has a bimodal type rainfall. Similar to the northwestern and central highlands, the climate of this region is broadly characterized by the recurrence of wet and dry seasons which are determined by the annual movements of the equatorial low pressure zones (ITCZ) across the country (FAO, 1989; Markin et al., 1975; Mamo, 2005). The major precipitation phenomenon in the area is, therefore, governed by the interaction outcomes of the macro pressure systems emanating from the subtropical regions of the two hemispheres. According to Mamo (2005), the weather in the region becomes unstable and convergence of moist southeasterly winds originating from Indian Ocean with the weakening northeasterly dry air stream causes rainfall to occur over most parts of this region in the spring seasons of MAM. While the ITCZ continues migrating towards northern Ethiopia, the further advancement of moist air mass incursion from both Indian and Atlantic Oceans makes the area to receive rainfall during the main rainy season of JJAS period (NMSA, 1996a & b). The central rift valley region is also subjected to same Atlantic and Indian Ocean influence.

To our knowledge, the most reliable evidence about the status of climate change with focus on rainfall changes is results of the indirect studies done on the hydrology of tributary rivers and nature of the lakes' level fluctuation. For example, climate change sensitivity study by Hailemariam (1999) on Awash River showed that there is a reduction tendency in flow and the river is highly vulnerable to climate change. Climate change impact studies on the tributary rivers of Ziway Lake (Meki and Katar) by Abraham (2006) also showed that there is a decrease in flow in the region and this again gives another witness of precipitation decline in the area although most of the studies and their results emphasized on the impacts of land use land cover change rather than giving sufficient room for climate issues. The lake level fluctuations are claimed to be attributed to changes in the precipitation conditions over the adjacent highlands (street 1979) from which tributary rivers and streams are radiating towards the low-lying rift lakes and rainfall in the region is contended that it has no substantial declining trend in the last four decades (Ayenew, 2004). Nevertheless, the situation in Lake Awassa seems a bit masked by the severe neo-tectonic activities around the lake area. For instance, the hydro-geological study at Lake Awassa and its catchment area done by Geremew (2000) and Ayenew (2004) show that there is lake level rise but this cannot be correlated with climate variables. The corollary of these findings is that the rise in lake level is not positively correlated with precipitation in the area. Instead some studies (Tessema, 1998, Ayenew, 1998, 2001a, Ayalew et al., 2004) on groundwater resources in the rift faults indicated the positive role of open tensional faults and ground cracks in the substantial transfer of groundwater to the lakes. A counter example is the ground cracks created in the Muleti area of southwest of Lake Awassa which have been found to be the major conduits to groundwater transfer from a small Derba pond (an area about 5 Km^2) into Awassa lake (Gebreegziabher, 2004) and the small pond is seen disappeared in less than two years after the formation of these cracks. The premises of all these studies on the lake gives the impressions of either the presence of very small declining trend of precipitation or the consistency of it around the Lake. The result of this paper is in line with the first plausible case because the small declining trend cannot bring significant change on the level of the lake due to the high inflow compensation of water from ground water sources to the lake.

The southern parts of the rift valley (Arba Minch and Dilla areas) have shown an increasing trend in rainfall. Being present in the same geographical region of the country, this region has many similar external as well as internal land features to that of the central rift valley regions. However, the nature and seasonality of precipitation is quite different from northern part of the rift vally. Of course, analogous to the central rift valley, rainfall in this part of the valley and other southeastern lowlands of the country has bimodality in nature. But the periods of wet seasons are different. The first wet season which is more prominent than the second, due to the relatively slow northward movement of the ITCZ as it is the case in other East African regions, runs from March to May and the second short wet season is from October to November which is caused by the rapid southward migration of the ITCZ (Black et al., 2003). There is an extended dry time in the months of JJAS when the other parts of the country receive heavy rains. This is because of the extended effects of the ITCZ around the equatorial East African region. As this part of the country is near to the equator, in which the ITCZ crosses twice while it propagates north and retreats back. This makes the rain in southernmost and eastern Ethiopia to have the characteristics of East African rains.

There are a few hydro-geological studies around the lakes of Abaya and Chamo and studies on the nature of the East African rainfall. The studies on the hydro-geology of the area in general and about the situation in the rise and fall of Abaya and Chamo lake levels in particular have paramount importance in understanding the status of precipitation in the area. Although there are some controversies of the results, most of the study results claimed that there is lake level rise in Abaya and Chamo since the beginning of the last two decades of the 20^{th} century (Schütt et al., 2002; Ayenew, 2004). But the attribution for the rising water level of these lakes is believed to be nonclimatic factors like population pressure, deforestation and a change in cultivation manner as well as neotectonics. As land use land cover change is increased due to the expansion of extensive irrigation practices, no one can deny the possible change on an increase in surface runoff and groundwater flux from percolated irrigated fields which will have again positive impacts in increasing the level of lakes. As a result, local anthropogenic factors are blamed to be responsible for leading to an increase in sediment yield of the Lake Abaya's tributaries and this influences basin bathymetry and volume. Moreover, as compared to climatic factors, the role of neo-tectonic activity in uplifting of the sill departing the basins of Lake Abaya and Lake Chamo is given great priority by many scholars. The rise in the sill is expected to control Lake Abaya's outflow (Schütt et al., 2002) and the recent lake level rise in Abaya is accounted to the overall combinations of anthropogenic and neotectonic factors. The neotectonic factor seems hold true if there is a corresponding lake level decline in Lake Chamo which is endhoric and mainly fed by the overflow of Lake Abaya. Ironically, recent studies show that there is also a rise in water level of Lake Chamo (Ayenew, 2007). All of these studies seemed a bit contradictory that it is difficult to take nonclimatic factors alone as the possible attributes for the lake level rises in Abaya. On the contrary, our study shows the presence of significant rainfall increases in the area which could partly explain lake level rises.

The second most reliable (even if they are indirect) sources which encourage the presence of rainfall increase in southern rift valley areas are studies on pluvmetric properties of the East African region since rainfall in southernmost Ethiopia has a typical character of the southern and equatorial east African rainfall (Black et al., 2003; Lemma, 2003; Ummenhofer, 2008).

Because of its geographical proximity, the influence of Indian Ocean on East African rainfall is much more immediate than any other region in Africa. As it was concluded in the works of (WCRP, 2006), the tropical Indian Ocean and the subtropics off western Australia have warmed over the 20th century, and the rate of warming has accelerated substantially during the last 30 years. This advocates convective instability and cyclone formation over the ocean. As a result, rainfall increases over East Africa due to enhanced convective heating from the Indian Ocean causing anomalous cyclonic circulation conditions to the southeast of Africa with southeasterly moisture influx onto East Africa (Goddard and Graham, 1999). This is despite the influence of the Indian Ocean which can be modulated by remote forcing from the central and eastern tropical Pacific Ocean. For instance, rainfall was found to be greater during El Nino years than the long-term mean over East Africa in general and lake Victoria in particular (Ogallo, 1988) and this shows the indirect impacts of Pacific Ocean on East African rainfall. Hence, in conjunction with these phenomena, rainfall seems to have an increasing tendency in southern rift valley regions of Ethiopia.

Another major factor which may be accounted for the increase of rainfall in southern rift valley is the role of the Somali jet. The Somali jet is a low level strong southeasterly wind which develops predominantly as a result of the cold upwelling coastal water near the Horn and the differential heating in East African highlands. Due to the consequence of global climate change, Indian Ocean warms significantly and there is a very likelihood of temperature increase in all parts of Africa. This has paramount implications to the most topographically diversified regions of east Africa and the Horn region. Highlands are expected to warm more severely than lowlands in the region because of the thermal equilibrium tendency of the natural system. This has a negative impact on the strength of the Somali Jet and inhibits its moisture transport capacity to the highland areas of Ethiopia. The weakening of the Somali Jet to launch its moisture transport to the far northern and central highlands of Ethiopia will pave a road for the increase in moisture convergence in the southern rift valley areas of the country via the Turkana Channel (Vizy and Cook, 2003). The moisture laden air transported via this channel converges over the southern slopes of the Ethiopian highlands and which ultimately increases moisture convergence as well as rainfall rates over southern Ethiopia as claimed in the model works of Vizy and Cook (2003).

As there are major inland lakes in east African rift valley region, they have the potential to influence their surrounding climates. For instance, the latest IPCC report claims that, despite of the very likelihood of temperature increase in all parts of Africa, temperature measurements from weather stations located close to the coast or to major inland lakes in East Africa have been decreasing (IPCC, 2007b). This may be attributed to the special thermal property of water, which facilitates intense evaporation above the lakes as claimed by King Uyu et al. (2000) thereby results in the increase in tropical precipitation intensity (Meehl et al., 2000).

Recent climate model studies around the major inland lakes of East Africa have shown that there is a wetting trend over the 20th century in rift areas of northern Kenya and southern Ethiopia as well as around their vicinity and this is the case in both rainfall seasons (www.knmi.nl/africa_scenarios).
According to this study, even some small-scale in-homogeneities in rainfall caused by local features (such as mountains and lake-land contrasts) and short-term fluctuations do not hide this trend. Future predictions of climate models also show that there will be a continuation of the wetting trend over much of East Africa during both seasons and the simulated annual cycle shows that it is the rainfall intensity in a given season that is likely to increase but not the change in the duration of the rainy season (www.knmi.nl/africa_scenarios). We have exhaustedly reviewed the work of other scholars on the nature of rainfall trend in southern rift valley regions. Despite the fact that there are some ambiguities on the possible attribution factor, almost all the findings agree on the increasing trend of precipitation in the region.

5 Conclusions

The good quality of the gridded rainfall data set is manifested in its capacity to capture the dominant seasonal cycles and rainfall distribution using harmonic analysis. The data set reveal led the monomodal and bimodel rainfall types and their areas of influence in a more robust way than previous studies.

The primary concern of this paper was detecting the status of climate change manifestation phenomena at local scale in Ethiopia. Rainfall records from rain gauges of over 190 stations are used to produce homogeneous gridded data set, considered for the study. The monthly time series data of gridded data set are analyzed by harmonic analysis to see the dominant seasonal cycles. SSA is used to extract slow varying trend components. Mann-Kendall test was applied for statistical significance of trend. The results reveal that almost all of the country show a significant trend at both 95% and 99% significant levels which are either decreasing or increasing.

Spatially, the western half of northern and central Ethiopia have shown declining trend in rainfall. The northeastern part of the country and very small localized places of western Ethiopia have exhibited a rise in rainfall. The trend in the rift valley area of the country has shown a tripole pattern in which the central rift valley area has decreasing rainfall trend where as the southern and northeren rift valley have exhibited increasing rainfall trend.

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